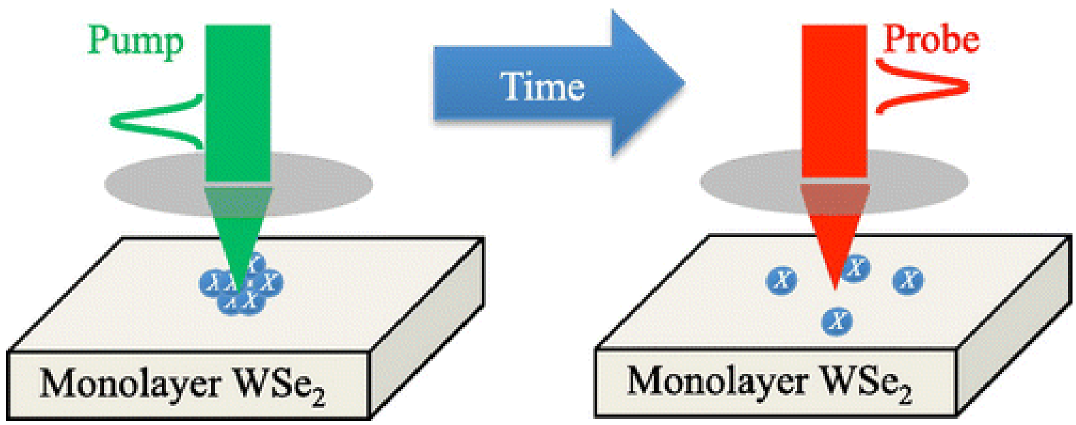
Using strong lasers, investigators observe frenzy of electrons in a new material

April 15 2014, by Brendan M. Lynch



(Phys.org) —A research team at the University of Kansas has used high-powered lasers to track the speed and movement of electrons inside an innovative material that is just one atom thick. Their findings are published in the current issue of *ACS Nano*, a peer-reviewed journal focused on nanoscience.

The work at KU's Ultrafast Laser Lab could help point the way to next-generation transistors and solar panels made of solid, atomically thin materials.

"When the solid is a thin layer, electrons are confined in this thin layer," said Hui Zhao, associate professor of physics and astronomy, who leads the team. "An electron that is free to move in two dimensions behaves very differently from those moving in all the three dimensions. It totally changes how electrons interact with environment. Under the right conditions, electrons moving in two dimensions are less likely to collide with other things in the solid, and hence their motion is less disrupted. Faster electron motion often leads to better performance of devices."

To monitor the electrons, Zhao and graduate students Qiannan Cui, Frank Ceballos and Nardeep Kumar created a single-atom layer of tungsten disulphide, a material used in solar cells and as a lubricant.

The KU researchers produced the single atomic layer by employing the "Scotch tape method" first used by scientists working at the University of Manchester to create "graphene," a material that earned its creators the Nobel Prize for physics in 2010.

"Tungsten diselenide is one of the a few atomically thin materials that are known to be stable under ambient conditions," Zhao said. "We don't have many choices. Most materials cannot stay at a single-atomic-layer format. They will break or convert to other forms."

Once the team created a single-atom-thick flake of the tungsten diselenide, they arranged about 100 mirrors, lenses and crystals on a vibration-free table to create a transient absorption microscope. Next, they focused an ultrashort laser pulse—with a duration of only one-tenth of one-billionth of a second—on the sample. Hundreds of electrons in a one-square-micrometer area of the material absorbed the laser's energy and become energetic enough to move freely in the sample.

"Their motion is similar to those energetic kids, except they move much faster and collide much more frequently," said Zhao.

The team's ability to track the motion of the electrons and determine their speed is the most important breakthrough of the investigation.

"To follow the motion of these energetic electrons, we used another laser pulse to track the location of these electrons at every one-billionth second until they lost their energy and settled down," Zhao said. "The measurement was repeated 80 million times per second automatically in order to average out the noise. We found that the electrons collide with other particles about 4 billion times per second, on average."

The speed of electrons in a material is one of the most important electronic properties, according to the researcher.

"It translates for faster operation in logic devices and computers, higher efficiency in solar cells and better sensitivity in sensors," said Zhao. "Being able to measure this quality is the first step to understand any limiting factors and how to improve upon them. Other researchers deduce electron motion by measuring current versus voltage. It's less direct and requires connecting the semiconductor to electrodes. This can be very hard for small and thin samples. Our approach is direct and noninvasive."

Not content to simply monitor the electrons' activity, Zhao and his team hope to boost the performance of electrons in order to bring about more efficient, powerful electronic devices than the current generation that utilize silicone as the transistor material.

"Our next goal along this line is to find ways to increase the electron speed by, for example, putting the single layers on a more suitable substrate or modifying the material," he said. "Another direction is to use this material, along with others, to form new, manmade 3-D crystals. It's possible that such crystals will be developed in the next a few years, because many groups are working on it. It's hard to predict when this can be commercialized. This is just one potential solution to replacing silicon for electronics industry. The current aim is to learn how to improve materials' quality, reduce the cost and try to understand their advantages and drawbacks."

More information: Transient Absorption Microscopy of Monolayer and Bulk WSe2, *ACS Nano*, 2014, 8 (3), pp 2970–2976. DOI: 10.1021/nn500277y

Abstract
We present an experimental investigation on the exciton dynamics of monolayer and bulk WSe2 samples, both of which are studied by femtosecond transient absorption microscopy. Under the excitation of a 405 nm pump pulse, the differential reflection signal of a probe pulse (tuned to the A-exciton resonance) reaches a peak rapidly that indicates an ultrafast formation process of excitons. By resolving the differential reflection signal in both time and space, we directly determine the exciton lifetimes of 18 ± 1 and 160 ± 10 ps and the exciton diffusion coefficients of 15 ± 5 and 9 ± 3 cm2/s in the monolayer and bulk samples, respectively. From these values, we deduce other parameters characterizing the exciton dynamics such as the diffusion length, the mobility, the mean free path, and the mean free length. These fundamental parameters are useful for understanding the excitons in monolayer and bulk WSe2 and are important for applications in optoelectronics, photonics, and electronics.

Provided by University of Kansas